Chapter 8

Groundwater Investigation and Remediation

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During 2006, groundwater investigations and remediations under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) continued at both the Livermore site and Site 300. Lawrence Livermore National Laboratory samples and analyzes groundwater from areas of known or suspected contamination. Portions of the two sites where soil or groundwater contains or may contain chemicals of concern are actively investigated to define the hydrogeology and nature and extent of the contamination and its source. Where necessary, remediation strategies are developed and evaluated in preparation for a CERCLA removal action or through the feasibility study process. An approved remedy for each area is developed in consultation with the regulatory agencies and the community.

This chapter reviews the distribution of contaminants in groundwater and the progress LLNL has made in removing contaminants from groundwater and from the unsaturated zone (soil vapor) at the Livermore site and Site 300. The sites are similar in that the contamination is, for the most part, confined to on site. The sites differ in that Site 300,

with an area of 28.3 square kilometers (km^2), is much larger than the Livermore site and has been divided into eight operable units based on the nature and extent of contamination, and topographic and hydrologic considerations. The Livermore site at 3.3 km^2 is effectively one operable unit.

8.1 Livermore Site Ground Water Project

Initial releases of hazardous materials occurred at the Livermore site in the mid-to-late 1940s during operations at the Livermore Naval Air Station (Thorpe et al. 1990). There is also evidence that localized spills, leaking tanks and impoundments, and landfills contributed volatile organic compounds (VOCs), fuel hydrocarbons, metals, and tritium to the unsaturated zone and groundwater in the post-Navy era. The Livermore site was placed on the U.S. Environmental Protection Agency National Priorities List in 1987.

An analysis of all environmental media showed that groundwater and both saturated and unsaturated soils are the only media that require remediation (Thorpe et al. 1990). Compounds that currently exist in groundwater at various locations beneath the site at concentrations above drinking water standards (maximum contaminant levels [MCLs]), are trichloroethylene (TCE), perchloroethylene (PCE), 1,1-dichloroethylene, chloroform, 1,2-dichloroethylene, 1,1-dichloroethane, 1,2-dichloroethane, trichlorotrifluoroethane (Freon-113), trichlorofluoromethane (Freon-11), and carbon tetrachloride. PCE is also present at low concentrations slightly above the MCL in several off-site plumes that extend from the southwestern corner of the Livermore site. LLNL operates groundwater extraction wells in both on- and off-site areas. In addition, LLNL maintains an extensive network of groundwater monitoring wells in the off-site area west of Vasco Road.

8.1.1 Physiographic Setting

The general topography of the Livermore site is described in **Chapter 1**. The Livermore Valley groundwater system consists of several semiconfined aquifers. Rainfall from the surrounding hills and seasonal surface water in the arroyos recharges the groundwater system, which flows toward the east-west axis of the valley.

The thickest sediments and aquifers are present in the central and western portions of the Livermore Valley, where they form an important resource for the Zone 7 Water Agency. These sediments comprise two aquifers: the Livermore Formation and overlying alluvium. The Livermore Formation averages about 1000 meters (m) in thickness and occupies an area of approximately 250 km^2. The alluvium, which is about 100-m thick, is the principal water-producing aquifer within the valley.

8.1.2 Hydrogeology of the Livermore Site

Sediments at the Livermore site are grouped into four grain-size categories—clay, silt, sand, and gravel. Groundwater flow beneath the site occurs primarily in alluvial sand and gravel deposits, which are bounded by lower permeability clay and silt deposits. The alluvial sediments have been subdivided into nine hydrostratigraphic units (HSUs) beneath the Livermore site (see **Figure 8-1**). HSUs are defined as sedimentary sequences whose permeable layers show evidence of being hydraulically interconnected. Six of the nine HSUs contain contaminants at concentrations above their MCLs: HSU-1B, -2, -3A, -3B, -4, and -5 (Blake et al. 1995; Hoffman et al. 2003). HSU-1A, -6, and -7 do not contain contaminants of concern above action levels and are therefore not discussed further.

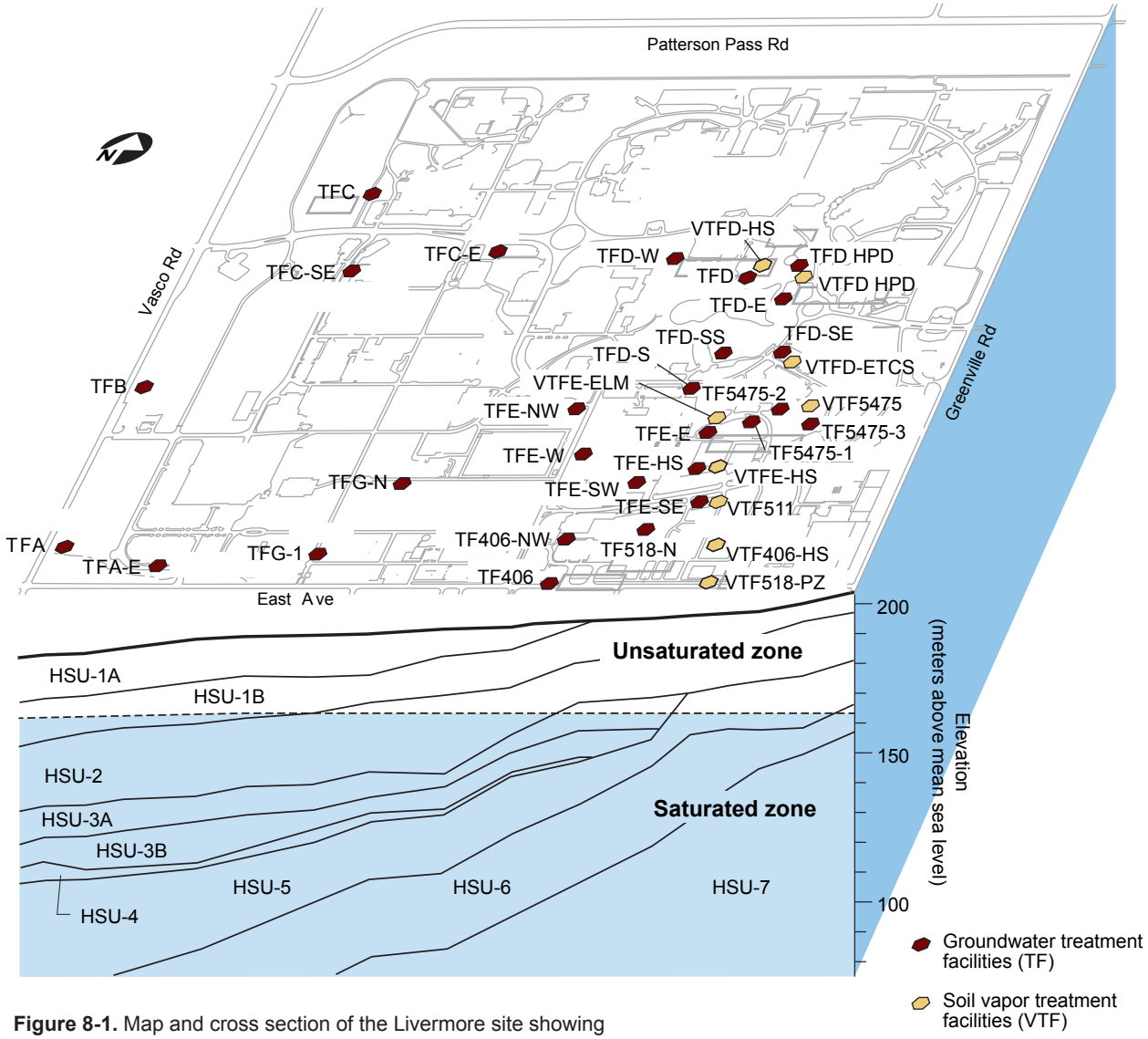


Figure 8-1. Map and cross section of the Livermore site showing hydrostratigraphic units and the location of the treatment facilities.

8.1.3 Remediation Activities and Monitoring Results

This section summarizes the primary activities and results of the Livermore site Ground Water Project in 2006. Additional information is provided in Karachewski et al. (2007). In addition to discussing trends during the past year, this section also highlights the significant reduction of VOC concentrations at the Livermore site during the past five years.

In 2006, LLNL operated 27 groundwater treatment facilities (see **Table 8-1** and **Figure 8-1**). The 92 groundwater extraction wells and 34 dual extraction wells produced more than 1059 million liters (L) of groundwater and the treatment facilities removed nearly 78 kilograms (kg) of VOCs (see **Table 8-1**). In 2005, the groundwater treatment facilities removed approximately 71 kg of VOCs. The higher mass removal in 2006 is due to the addition of new extraction wells to existing or upgraded treatment facilities in contaminant source areas. Since remediation began in 1989, approximately 11,838 million L of groundwater have been treated, resulting in removal of more than 1246 kg of VOCs.

In 2006, LLNL also operated 9 soil vapor treatment facilities (see **Table 8-1** and **Figure 8-1**). The 19 soil vapor extraction wells and 34 dual extraction wells produced more than 2.3 million cubic meters (m^3) of soil vapor and the treatment facilities removed more than 177 kg of VOCs (see **Table 8-1**). In 2005, the soil vapor treatment facilities removed approximately 196 kg of VOCs. The lower rate of mass removal in 2006 is due to decreasing VOC concentrations and cleanup of the vadose zone in the TFD and TFE source areas. However, there was a significant increase in VOC mass removed in the TFH source areas, from 110.5 kg in 2005 to 151.2 kg in 2006. This increase was due to the ongoing operation of existing treatment facilities, especially at VTF406 Hotspot, and startup of a new treatment facility at VTF511. Since initial operation, over 7 million m^3 of soil vapor has been extracted and treated, removing more than 1052 kg of VOCs from the subsurface.

Over the last five years, groundwater VOC concentrations in HSU-1B, -2, and -3A along the western and southern margins of the Livermore site have continued to decline, particularly in the off-site areas, due to the combined effects of hydraulic capture and groundwater treatment. The concentration decline in HSU-2 over the last five years is shown in **Figure 8-2**. In the interior of the site, aggressive implementation of pump and treat remediation using portable treatment units positioned downgradient of source areas has resulted in concentration declines in HSU-2, -3A, -3B, -4, and -5.

Over the last four years, remediation activities, including soil vapor extraction, dual extraction, and groundwater extraction, have focused increasingly on source area cleanup. The annual amount of VOC mass removed from source areas in response to these cleanup activities has nearly doubled over this period. **Figures 8-3** and **8-4** show the amount of VOC mass removed and volume of groundwater extracted at the Livermore site since remediation activities began in 1989.

In 2006, concentrations continued to decrease in most Livermore site VOC plumes. The decline in VOC concentrations is attributed primarily to active remediation and removal of

Table 8-1. VOCs removed from groundwater and soil at the Livermore site.

Groundwater/ soil vapor	Treatment facility area[a]	2006		Cumulative Total	
		Water treated (million L)	VOCs removed (kg)	Water treated (million L)	VOCs removed (kg)
Groundwater	TFA	365.5	5.7	5293.3	184.3
	TFB	97.3	2.7	1220.1	68.4
	TFC	148.2	6.2	1112.5	78.1
	TFD	280.7	46.4	2648.3	696.3
	TFE	99.1	11.1	947.4	183.5
	TFG	27.2	1.1	169.8	8.3
	TFH	41.1	4.6	446.3	27.2
	Total[b]	1059	78	11,838	1246
		Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)	Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)
Soil vapor[c]	TFD	584.9	14.3	1180.5	80.2
	TFE	1037.9	11.8	2912.7	134.8
	TFH	736.4	151.2	3228.9	837.3
	Total[b]	2359	177	7322	1052

(a) Treatment areas and facilities:

TFA area: TFA, TFA-E

TFB area: TFB

TFC area: TFC, TFC-E, TFC-SE

TFD area: TFD, TFD-E, TFD-HPD, TFD-S, TFD-SE, TFD-SS, TFD-W, VTFD-ETCS, VTFD-HPD, VTFD-HS

TFE area: TFE-E, TFE-HS, TFE-NW, TFE-SE, TFE-SW, TFE-W, VTFE-ELM, VTFE-HS

TFG area: TFG-1, TFG-N

TFH area: TF406, TF406-NW, VTF406-HS, VTF511, TF518-N, VTF518-PZ, TF5475-1, TF5475-2, TF5475-3, VTF5475

(b) Totals rounded to nearest whole number.

(c) Includes only those treatment areas at which vapor was extracted.

more than 255 kg of VOCs by the groundwater and soil vapor extraction wells and treatment facilities during the year. Notable trends and results are discussed below.

VOC concentrations on the western margin of the site generally continued to decline slowly, indicating continued hydraulic control of the boundary plumes in the TFA, TFB, and TFC areas. Off-site, VOCs in HSU-1B remained below MCLs, except at well W-1425, which is currently fluctuating above and below the PCE MCL (1.2 parts per billion [ppb] PCE, December 2006). A large area east of the TFA north pipeline (including wells W-115, W-213, and W-604) fell below MCLs for the first time. The entire off- and on-site TFA HSU-2 VOC plume remained below 25 ppb in 2006. The highest PCE levels off-site continue to be at wells W-404 and W-654, where maximum 2006 concentrations were 24 ppb and

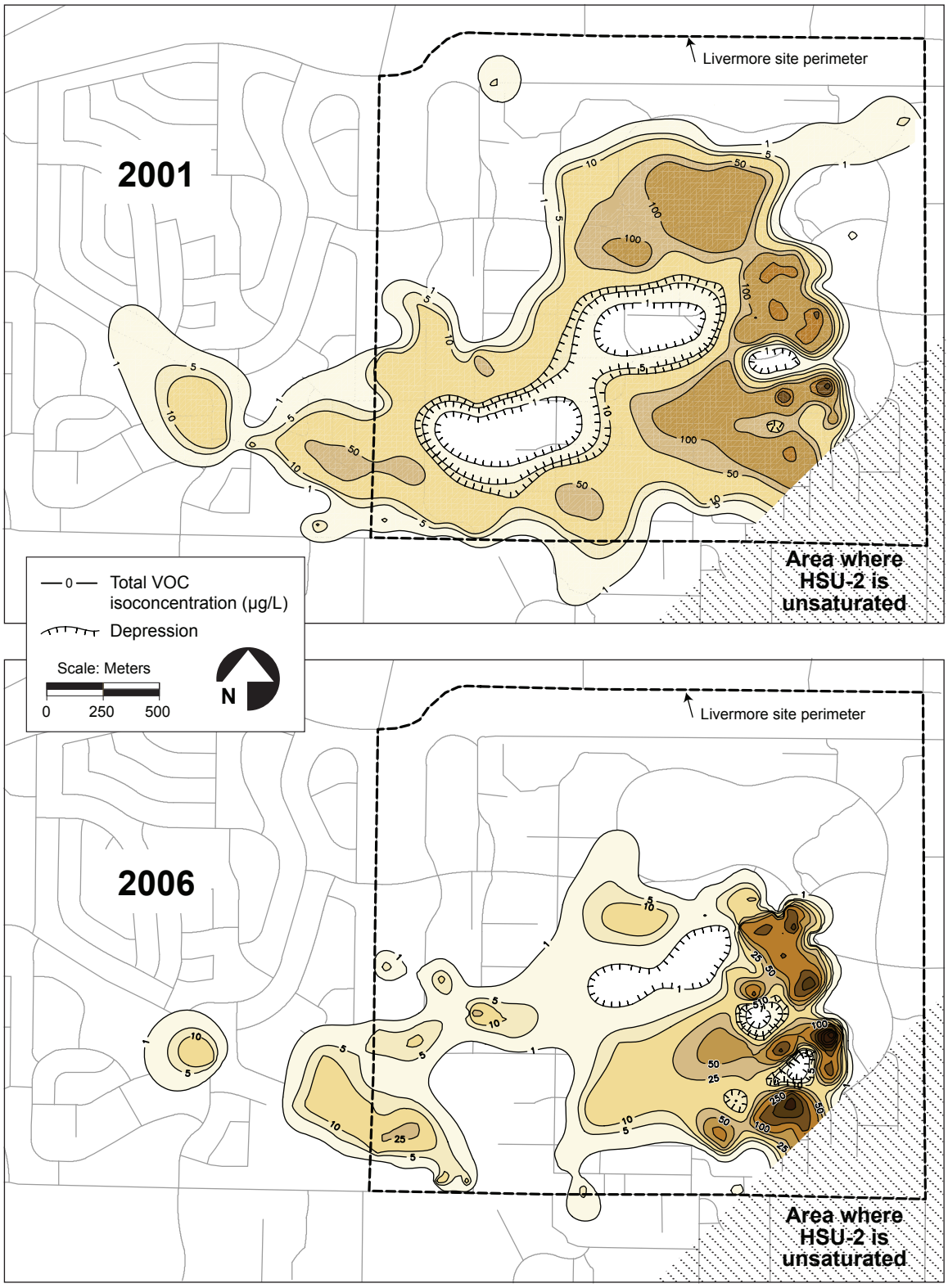


Figure 8-2. Isoconcentration maps showing reductions in total VOCs above MCLs for HSU-2 between 2001 and 2006.

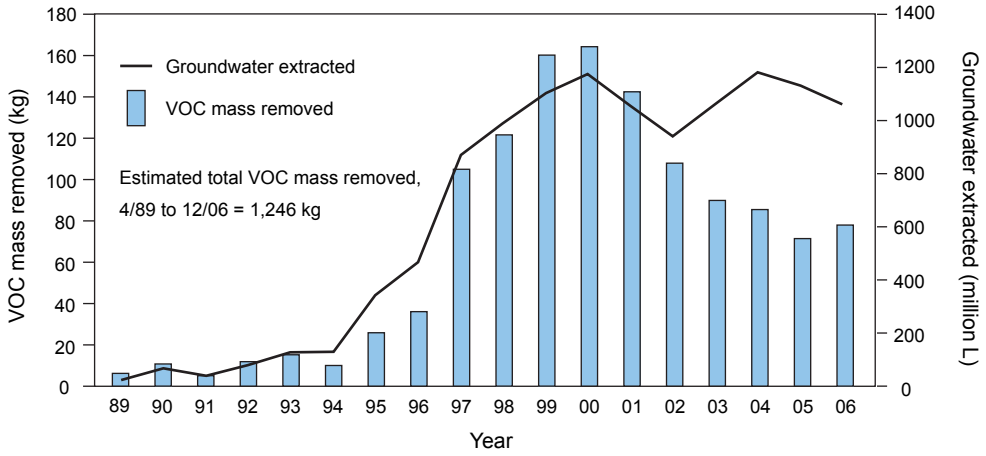


Figure 8-3. Estimated total VOC mass removed from groundwater at the Livermore site subsurface since 1989.

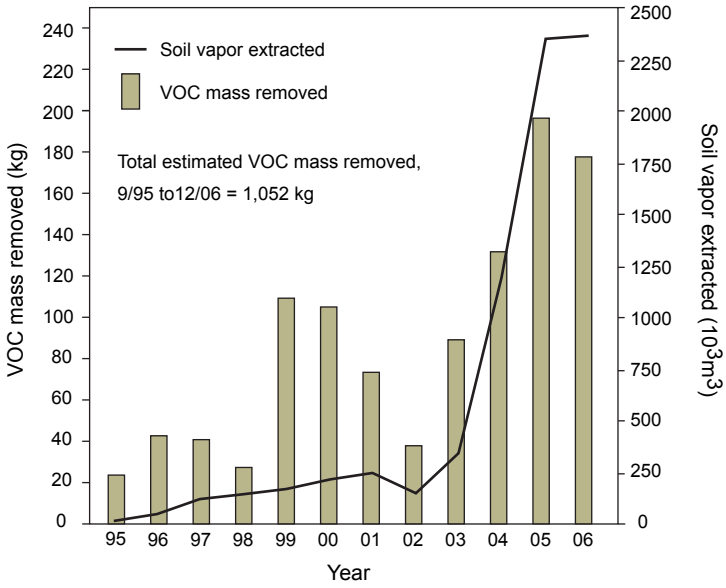


Figure 8-4. Estimated total VOC mass removed from soil vapor at the Livermore site subsurface since 1995.

13 ppb, respectively. To ensure hydraulic containment and to reduce the concentration of PCE at well W-404, TFA West was activated in January 2007. At TFB, concentrations rose along the western margin at well W-422 (9.6 ppb TCE, December 2006). A hydraulic test is being conducted to determine whether additional groundwater extraction will be required to prevent off-site migration of the VOC plume at this location. Concentrations in all TFA, TFB, and TFC source areas remained relatively unchanged, except at the TFC Hotspot area where TCE increased from 260 ppb (October 2005) to 300 ppb (July 2006) in HSU-1B well SIP-501-007. Groundwater remediation began in this area in April 2006 as part of the TFC Hotspot milestone.

VOC concentrations in a mobile HSU-2 plume located in the central TFE area increased slightly over the last year. Concentration increases observed at wells W-1202 (from 43 ppb to

79 ppb TCE), W-271 (from 23 ppb to 29 ppb TCE) and W-1508 (from 17 ppb to 32 ppb TCE) should be hydraulically captured and treated at downgradient treatment facility TFE-W. TCE concentrations in this plume's source area, TFE Eastern Landing Mat, declined over the last year from 1600 ppb to 1400 ppb in well SIP-543-101 due to ongoing operation of soil vapor and dual extraction wells.

The entire HSU-3A TFD area Freon-11 plume dropped below MCLs for the first time in response to groundwater extraction at TFD West. In the TFB area, PCE and TCE increased slightly in HSU-3A well W-310 (to 5.7 ppb and 3.4 ppb, respectively). Hydraulic testing is planned to determine the cause of this increase. After increasing for several years, TCE concentrations at TFE well W-276 declined slightly during 2006, probably due to ongoing groundwater extraction and treatment at TF406 Northwest. The W-276 area will continue to be evaluated to determine whether hydraulic containment and groundwater treatment is needed to prevent westward migration of this plume into an area with limited well control. In the Building 419 area, concentrations in source area well W-1414 declined from 3000 ppb to 1500 ppb TCE. Soil vapor cleanup in the Building 419 source area began in September 2006. Elsewhere in HSU-3A, VOC concentrations remained largely unchanged.

Concentrations in the HSU-3B plume emanating from the TFD Southeast area increased slightly during 2006. TCE concentrations at extraction well W-1403 rose from 420 ppb to 490 ppb, while TCE at downgradient monitor well W-1511 increased from 270 to 390 ppb, then decreased to 270 ppb again. Groundwater extraction and treatment at TFD Southeast and at TFD South are expected to reduce these concentrations over time. Elsewhere in HSU-3B, VOC concentrations remained relatively unchanged.

Concentrations in HSU-4 generally declined in several areas under remediation. Near the south side of Trailer 5475, where groundwater extraction and treatment began in June 2006, TCE in extraction well W-1604 dropped from 2400 ppb to 350 ppb. At TFD Southeast, TCE in extraction well W-314 declined from 300 ppb to 250 ppb. TFD Main TCE concentrations in HSU-4 extraction well W-351 decreased from 310 ppb to 100 ppb, while at TFD Southshore, TCE declined in extraction well W-1523 from 320 ppb to 230 ppb. Elsewhere, concentration levels were relatively unchanged.

Concentrations continued to decline in HSU-5 on Sandia National Laboratories/California property in response to continued groundwater extraction at TF406, with only TCE remaining above its MCL in two off-site wells (11 ppb in well W-509 and 5 ppb in well W-1113). At extraction well W-359, TCE increased from 310 ppb to 390 ppb. Soil vapor extraction and dual extraction that began in the Building 511 source area in September 2006 is expected to reduce concentrations at well W-359 over time. Elsewhere in HSU-5, very little change was evident during 2006.

During 2006, tritium activities in groundwater from all wells at the Livermore site, including those in the Trailer 5475 and Building 292 areas, remained below the 740 becquerels per liter (Bq/L) (20,000 picocuries per liter [pCi/L]) MCL and continued to decline by radioactive decay.

8.1.4 Groundwater Flow and Transport Modeling

Groundwater flow and contaminant transport models were used at the Livermore site to optimize the design and operation of remediation systems; to support ongoing subsurface characterization activities; and to improve the ability to forecast, monitor, and interpret the progress of the remediation program.

The focus in 2006 was mainly on developing small-scale models that simulate multi-phase processes in the source areas. These models are capable of simulating the dual extraction remediation systems currently operating in the source areas. The source-area models, combined with the existing multi-dimensional regional-scale groundwater models, are used to optimize the operation of the dual extraction remediation systems. They also allow the evaluation of the potential benefit of using other conventional or innovative source-area cleanup technologies in the future. Pilot tests on one or more technologies are planned for 2007.

8.1.5 Environmental Impacts

At the Livermore site, LLNL strives to reduce risks arising from chemicals released to the environment, to conduct all its restoration activities to protect environmental resources, and to preserve the health and safety of all site workers. LLNL's environmental restoration project is committed to preventing present and future human exposure to contaminated soil and groundwater, preventing further contaminant migration of concentrations above drinking water standards, reducing concentrations of contaminants in groundwater, and minimizing contaminant migration from the unsaturated zone to the underlying groundwater.

Remedial solutions are implemented that have been determined to be most appropriate for individual areas of contamination. The selected remedial solutions have been agreed upon by DOE and the regulatory agencies with public input and are designed to achieve the goals of reducing risks to human health and the environment and satisfying remediation objectives, regulatory standards for chemicals in water and soil, and other state and federal requirements. These remedial solutions include groundwater and soil vapor extraction and treatment.

Groundwater and soil vapor extraction and treatment at the Livermore site continue to reduce the mass of contaminants in the subsurface. **Figures 8-3** and **8-4** show the VOC mass removed at the Livermore site from groundwater (since 1989) and from soil vapor (since 1995), respectively. In 2006, the groundwater and soil vapor treatment facilities removed more than 255 kg of VOCs. Since remediation efforts began in 1989, more than 11,838 million L of groundwater and more than 7.3 million m^3 of soil vapor have been treated, yielding a total of more than 2298 kg of removed VOCs.

8.2 Site 300 CERCLA Project

Environmental investigations and cleanup activities at Site 300 began in 1981. Site 300 became a CERCLA site in 1990 when it was placed on the National Priorities List. The CERCLA environmental restoration operable units (OUs) and groundwater contaminant plumes are shown in **Figure 8-5**. All characterized contaminant release sites that have a CERCLA pathway have been assigned to one of eight OUs based on the nature, extent, and sources of contamination, and topographic and hydrologic considerations. The major contaminants of concern for each OU are listed in **Table 8-2**. CERCLA work at Site 300 is conducted under a Federal Facility Agreement (FFA) and other requirements. Background information for LLNL environmental characterization and restoration activities at Site 300 can be found in Webster-Scholten (1994) and the *Site-Wide Remediation Evaluation Summary Report for Lawrence Livermore National Laboratory Site 300* (SWESR) (Ferry et al. 2006a). Key milestone and deliverable due dates for 2006 are listed in **Table 8-3**. All milestone and deliverable due dates were met during 2006. These milestones included

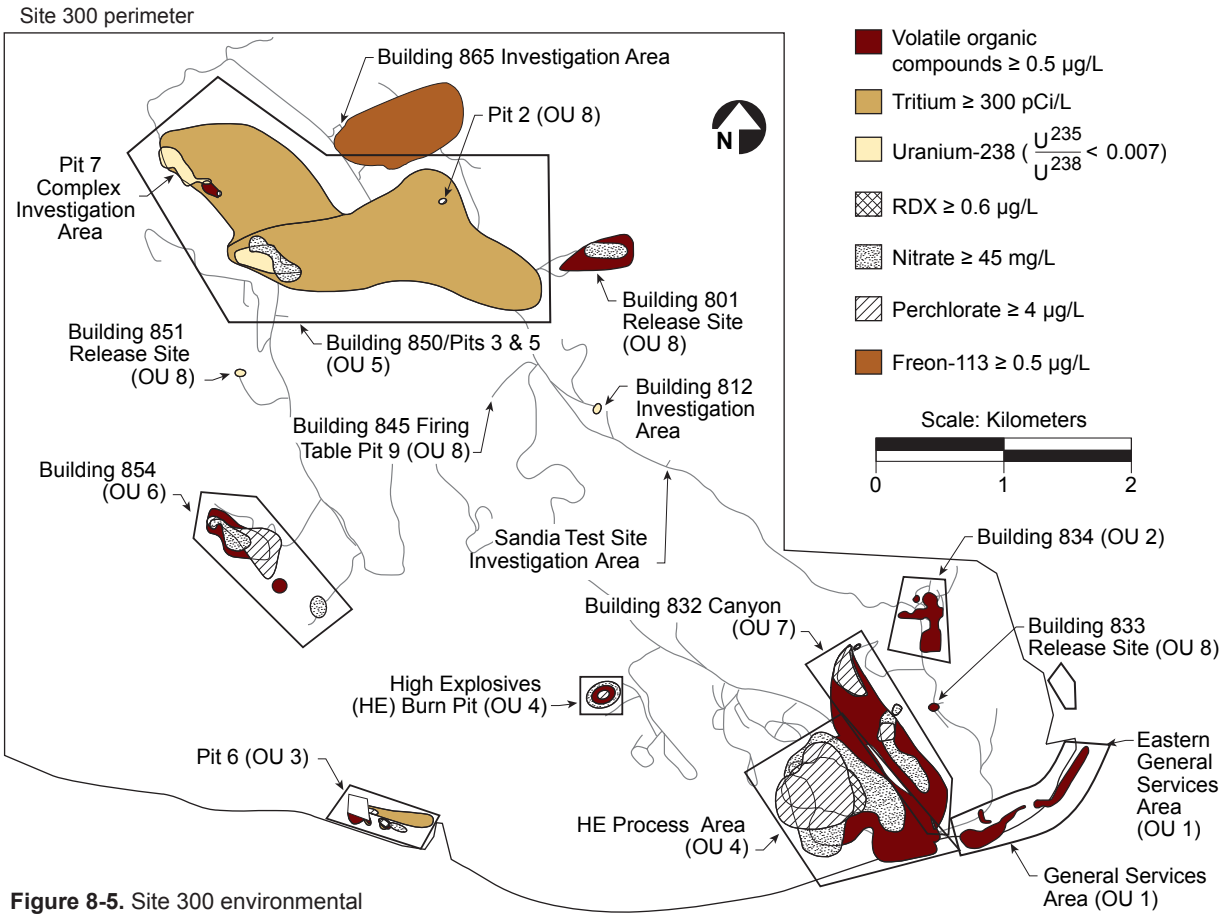


Figure 8-5. Site 300 environmental restoration operable units, investigation areas, and contaminants of concern.

Table 8-2. Major contaminants of concern found in soil, rock, and groundwater at Site 300.

Site	Contaminant of concern
General Services Area (GSA) (OU1)	VOCs (primarily TCE)
Building 834 Complex (OU2)	VOCs (primarily TCE), organosilicate oil, nitrate
Pit 6 (OU3)	VOCs (primarily TCE), tritium, nitrate, perchlorate
High Explosives Process Area (OU4)	VOCs (primarily TCE), high explosives (primarily RDX), nitrate, perchlorate
Building 850/Pit 7 Complex (OU5)	Tritium, depleted uranium, VOCs (primarily TCE), nitrate, perchlorate
Building 854 (OU6)	VOCs (primarily TCE), nitrate, perchlorate
Building 832 Canyon (OU7)	VOCs (primarily TCE), nitrate, perchlorate
Site-Wide Operable Unit (OU8)	VOCs (primarily TCE), nitrate, perchlorate, depleted uranium, tritium, metals, RDX
Building 865 Study Area	VOCs (primarily Freon-113)
Building 812 Study Area	Depleted uranium, nitrate, perchlorate
Sandia Test Site	None

Table 8-3. Calendar year 2006 deliverable and milestone dates for Site 300 environmental restoration activities outlined in the FFA and other agreements.

Deliverable/milestone	Due date
Final Building 832 Canyon Interim Remedial Design Report	2/23/06 (met)
Final Proposed Plan for the Pit 7 Complex	3/21/06 (met)
Draft Site-Wide Remediation Evaluation Summary Report	4/11/06 (met)
Public Meeting for the Proposed Plan for the Pit 7 Complex	4/20/06 (met)
Draft GSA 5-Year Review Report	5/3/06 (met)
Public Workshop for the Site-Wide Draft Remediation Evaluation Summary Report	5/16/06 (met)
Draft Amendment to the Interim Site-Wide Record of Decision (ROD) for the Pit 7 Complex	7/10/06 (met)
Expand B832-SRC groundwater extraction well field to the distal portion of the plume in the Building 832 Canyon OU	9/29/06 (met)
Hook-up B830-PRXN extraction well to the B830-SRC groundwater treatment system in the Building 832 Canyon OU	9/29/06 (met)
Expand B854-SRC groundwater extraction well field in the Building 854 OU	9/29/06 (met)
Expand B854-DIS groundwater extraction well field in the Building 854 OU	9/29/06 (met)
Building 865 (ATA) Characterization Summary Report	9/30/06 (met)
Final GSA 5-Year Review Report	10/30/06 (met)
Final Site-Wide Remedial Evaluation Summary Report	10/30/06 (met)
Draft Site-Wide Proposed Plan for the Final Record of Decision	12/8/06 (met)

submission of the SWESR, the *Draft Site-Wide Proposed Plan for the Lawrence Livermore National Laboratory Site 300 Final Record of Decision* (U.S. DOE 2006e), and the public workshop for the SWESR.

8.2.1 Physiographic Setting and Geology of Site 300

Site 300 is located in the sparsely populated Altamont Hills, which are part of the Coast Range Physiographic Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. Site 300 stratigraphy and hydrologic characteristics are shown in **Figure 8-6**. Rocks exposed in the region are classified into three groups:

- Late Tertiary-Quaternary (0–5 million years ago)—alluvium and semi-lithified sediments, mainly of continental origin
- Early to Late Tertiary (5–65 million years ago)—shallow marine and continental sedimentary and volcaniclastic rocks
- Jurassic-Cretaceous (65–180 million years ago)—Great Valley Sequence (marine sedimentary rocks and ophiolites) and Franciscan Complex (sheared and variably metamorphosed sedimentary and igneous rocks)

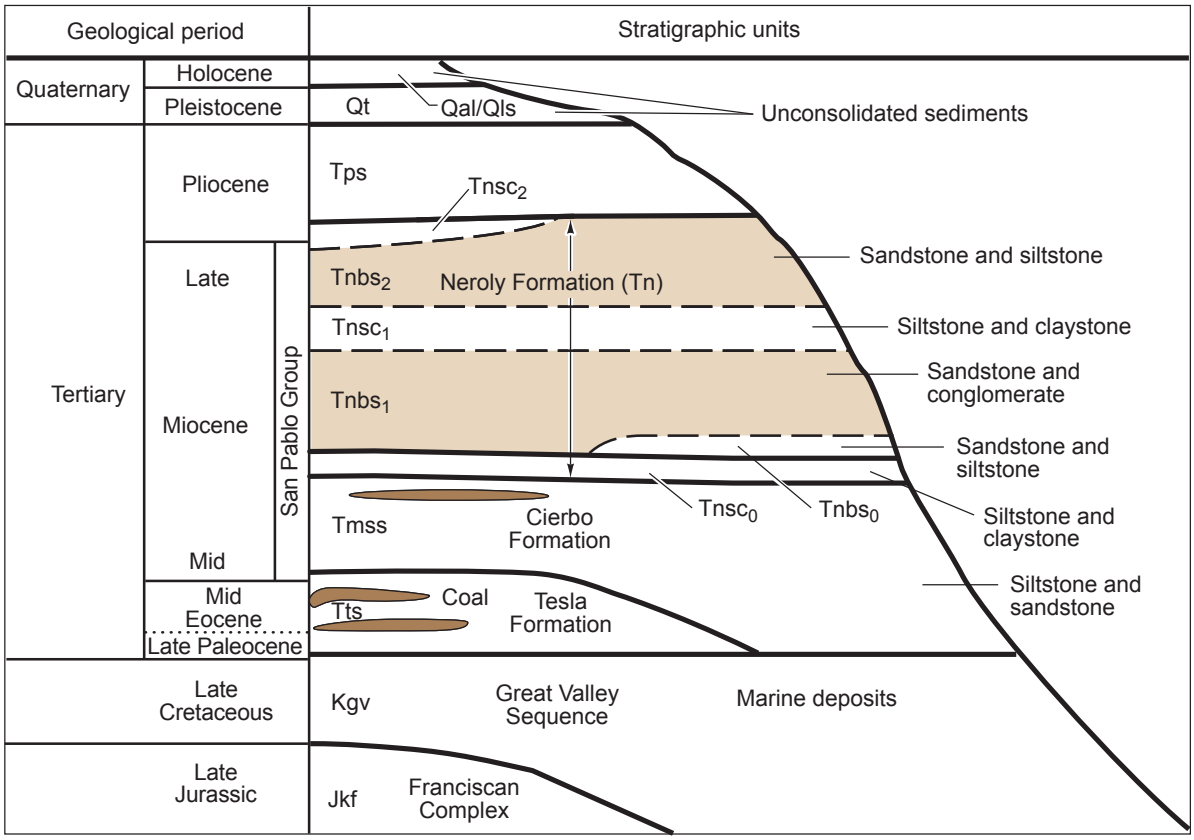
Distinctive volcaniclastic sandstone and sandy siltstone, interbedded with claystone and conglomerate, are exposed extensively within Site 300. These rocks are mapped as the late Miocene Neroly Formation. The Neroly Formation is also present in the subsurface beneath Site 300. It contains the principal hydrostratigraphic units (HSUs) within Site 300 and has been the focus of the detailed geologic and hydrogeologic studies conducted during recent years (summarized in Webster-Scholten 1994). These HSUs are described in Ferry et al. (2006c). The complete section of the Neroly Formation is about 150-m thick beneath Site 300.

The floodplain of Corral Hollow Creek lies along the southern boundary of Site 300 and borders portions of the General Services Area (GSA), the High Explosives Process Area, and the area of closed landfill Pit 6. Floodplain alluvium consists dominantly of coarse cobble-bearing terrace gravel derived from sources to the south, with lenses and local coverings of sandy silt and silty clay.

The bedrock sequence within Site 300 has been slightly deformed into several gentle, low-amplitude folds. The locations and characteristics of these folds, in combination with the regional fault and fracture patterns, locally influence groundwater flow within the site and have therefore been studied in great detail as part of the CERCLA investigations.

8.2.2 Contaminant Hydrogeology of Site 300

Site 300 is semiarid, with an average annual rainfall of 27 cm (10.6 in.). The site is underlain by gently dipping sedimentary bedrock dissected by steep ravines. The bedrock consists of interbedded conglomerates, sandstones, siltstones, and claystones. In addition to extensive water-bearing zones, some groundwater is present as perched water-bearing zones beneath



Hydrologic characteristics of stratigraphic units

Quaternary alluvium and underlying decomposed bedrock (Qal/WBR): Occurs in ravines and valley bottoms throughout Site 300. It is perennially saturated beneath Corral Hollow Creek, in Doall Ravine, and in southern Elk Ravine in the vicinity of Building 812. Groundwater also occurs in Qal/WBR in the Pit 7 Complex during the winter rainy season or during extended periods of higher than normal rainfall. Groundwater in this unit is unconfined.

Quaternary landslide deposits (Qls): Thin zones of unconfined groundwater occur locally beneath the Building 851 and Building 854 areas.

Quaternary terrace alluvium (Qt): Present and saturated at Pit 6, the GSA, and the Building 832 Canyon area; some of the groundwater occurrences are ephemeral.

Pliocene non-marine sediments (Tps/Tpsg): Saturated in the Building 833 and 834 areas and the Explosives Process Area. This bedrock unit is generally present only on hilltops. Where present, groundwater is typically unconfined, perched, discontinuous, and ephemeral. The exception to this condition exists in the Explosives Process Area, where the extent of saturation is significant.

Neroly Formation (Tn): Most extensive and saturated bedrock strata beneath Site 300. Unconfined to artesian conditions may exist. The formation is subdivided into the following units:

- Upper claystone/siltstone unit ($Tnsc_2$): Absent beneath much of Site 300. Saturated beneath the Building 834 area.
- Upper blue sandstone unit ($Tnbs_2$): Absent beneath much of Site 300. Saturated beneath Explosives Process Area.
- Lower siltstone/claystone unit ($Tnsc_1$): Saturated beneath Explosives Process Area, and Building 832 Canyon.
- Lower blue sandstone unit of the Neroly Formation ($Tnbs_1$): Primary water-bearing strata within the Neroly Formation. Saturated throughout Site 300, except in northeast portion, where it is absent. Fine-grained siltstone and claystone interbeds act as aquitards, confining layers, or perching horizons.
- Basal sandstone unit ($Tnbs_0$): Saturated beneath the Pit 7 Complex, Pit 2, and Building 801/Pit 8 areas.
- Basal siltstone/claystone unit ($Tnsc_0$): Saturated beneath the Building 854 area, and Building 845/Pit 9.

Cierbo Formation (Tmss): Groundwater occurs beneath Doall Ravine, the Building 850, 851, and 854 areas and the East Firing Area. The continuity of saturation between the northwest and southeast areas of Site 300 is undetermined. Groundwater occurs under unconfined to artesian conditions. Where saturation does not occur, fine-grained siltstone and claystone interbeds may act as aquitards, confining layers, or perching horizons.

Tesla Formation (Tts): Only found to contain groundwater immediately south of the Site 300 Pit 6 area.

Great Valley Sequence (Kgv): Groundwater not found in the few wells at Site 300 that penetrate the upper portion of the Great Valley Sequence.

Franciscan Complex (Jkf): No wells at Site 300 penetrate the Franciscan Complex**.**

Figure 8-6. Site 300 stratigraphy and hydrologic characteristics.

hilltops and valley bottoms. Groundwater flow in the bedrock follows the inclination, or dip, of the rock layers. The tectonic forces that uplifted the Altamont Hills faulted, gently folded, and tilted the once-horizontal sedimentary strata. A major structure, the east-west trending Patterson anticline, occupies a central location within the site. North of the anticline, bedrock generally dips east-northeast. South of the anticline, bedrock dips south-southeast. **Figure 1-4** (**Chapter 1**) is a map of the potentiometric surface for the first continuous water-bearing zone at Site 300, which principally occurs in the Neroly lower blue sandstone aquifer ($Tnbs_1$) and $Tnbs_0$. Portions of the bedrock section at Site 300 are abundantly fractured, and thus much of the groundwater flow occurs in fractures as well as in pores. Bedrock-hosted groundwater is typically present under confined conditions in the southern half of the site but is often unconfined elsewhere. Recharge occurs where saturated alluvial valley fill is in contact with underlying permeable bedrock, and where bedrock strata crop out. Low rainfall and high evapotranspiration rates, steep topography, and intervening aquitards generally preclude direct vertical recharge to the deeper bedrock aquifers.

All groundwater contaminant plumes at Site 300 occur in Neroly Formation (Tn) rocks, unnamed Pliocene non-marine sediments (Tps), or unconsolidated Quaternary sediments and weathered bedrock (Qal/WBR, Qls, or Qt) stratigraphic units. The extent of groundwater contamination at Site 300 is shown on **Figure 8-5**. **Figure 8-6** includes text that discusses the hydrologic conditions of strata at Site 300.

8.2.3 Remediation Activities and Monitoring Results

This section presents a summary of monitoring and remediation results for contaminant release sites at Site 300. Detailed monitoring and remediation results for the GSA, Building 834, High Explosives Process Area, Building 850, Building 854, Pit 6, Building 832 Canyon, and site-wide OUs are presented in Dibley et al. (2006b, 2007 [see **Appendix F]**). The SWESR (Ferry et al. 2006c) provides a comprehensive analysis of progress in achieving remedial action objectives (RAOs) at these contaminant release sites over the last five years. The results of investigations at the Pit 7 Complex, Building 865, Building 812, and Sandia Test Site are not included in the CMP reports and SWESR. Current information for each of these portions of Site 300 is presented at the end of this section.

At Site 300, there are 3 dedicated (non-portable) groundwater and soil vapor extraction and treatment facilities at the eastern GSA, central GSA, and Building 834 areas. There are also 16 portable treatment facilities at Site 300. All 19 facilities operated during 2006. Forty wells that extract only groundwater, 2 wells that extract only soil vapor, and 18 wells that extract both groundwater and soil vapor (dual-phase) were pumped and fed into treatment systems during 2006. In 2006, the 40 wells that extract only groundwater and the 18 wells that extract both groundwater and soil vapor yielded about 116 million L of groundwater. During the year, the 18 wells that extract both vapor and groundwater and the 2 wells that extract only vapor removed 2.25 million m^3 of vapor. In 2006, the Site 300 treatment facilities

Table 8-4. Volumes of groundwater and soil vapor extracted and masses of volatile organic compounds removed at Site 300 CERCLA Operable Units.

Groundwater/ soil vapor treatment	Operable Unit	Startup date	2006		Cumulative total	
			Water treated (million L)	VOCs removed (kg)	Water treated (million L)	VOCs removed (kg)
Groundwater treatment	GSA (OU1)	1991, 1993	94.1	0.55	1218	31.5
	Building 834 Complex (OU2)	1995	0.522	3.40	1.99	37.0
	High Explosives Process Area (OU4)	1999	15.5	0.207	54.9	0.789
	Building 854 (OU6)	1999	3.65	0.352	24.1	4.96
	Pit 6 (OU3)	1998	—[a]	—[a]	0.268	0.0014
	Building 832 Canyon (OU7)	1999	1.99	0.371	17.5	1.98
		Total[b]	116	4.84	1317	77.1
			Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)	Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)
Soil vapor treatment	Central GSA (OU1)	1994	256	0.700	2473	67
	Building 834 Complex (OU2)	1998	1336	35.0	3882	283
	Building 832 Canyon (OU7)	1999	121	3.90	553	5.7
	Building 854 (OU6)	2005	538	5.70	621	7.6
		Total[b]	2251	45.1	7528	364

(a) Groundwater treatment is not routine at Pit 6. A hydraulic pump test with a portable treatment unit for TCE removal was conducted there in 1998.

(b) Total may not be a sum of the column because of rounding error. Total values are taken directly from the data set to avoid compounding the rounding error.

removed approximately 50 kg of VOCs, 0.18 kg of perchlorate, 1000 kg of nitrate, 0.15 kg of RDX high explosive compound, and 0.029 kg of organosilicate oil. Since remediation efforts began in 1990, more than 1317 million L of groundwater and approximately 7.53 million m^3 of vapor have been treated, to yield about 433 kg of removed VOCs, 0.58 kg of perchlorate, 4400 kg of nitrate, 0.71 kg of RDX high explosive compound, and 9.4 kg of organosilicate oil. The 2006 and cumulative total volumes of groundwater and vapor extracted to Site 300 treatment facilities and VOC masses removed are tabulated in **Table 8-4**.

The eastern GSA and B830-DISS groundwater treatment facilities discharge to surface drainage courses. The B854-PRX solar treatment unit/containerized wetland, B854-DIS aqueous phase granular activated carbon (GAC), B815-DSB aqueous phase GAC, and B830-PRXN GAC treatment systems discharge to infiltration trenches. The B815-SRC, B815-PRX, B817-SRC, B817-PRX, and B829-SRC discharge to injection wells. The other nine treatment systems discharge to air by misting.

The GSA contains maintenance and shop facilities. Dry well and liquid storage activities yielded contaminants to groundwater. At the eastern and central GSA, the extraction

and treatment remedy continues to be effective and protective of human health and the environment, and to make progress toward cleanup. Groundwater total VOC concentrations in the Qal-$Tnbs_1$ HSU in the eastern GSA were reduced from a maximum of 74 µg/L in 1989 to 4.4 µg/L in December 2006. Current data indicate that pumping and treating groundwater from the three extraction wells in the eastern GSA has successfully reduced maximum concentrations of TCE and other VOCs in groundwater to below their cleanup standard (MCL) of 5 µg/L. Since extraction and treatment activities began at the eastern GSA in 1991, TCE concentrations in groundwater have decreased from an historical maximum of 74 µg/L to below analytical reporting limits of 0.5 µg/L in groundwater samples from most wells. Wells with water containing TCE concentrations exceeding the MCL have decreased from 18 to 0. DOE/LLNL has proposed to initiate the "Requirements for Closeout" described in the *Remedial Design Document for the General Services Area Operable Unit Treatment Facilities* (Rueth et al. 1998). These requirements specify that "when VOC concentrations in groundwater have been reduced to cleanup standards, the groundwater extraction and treatment system will be shut off and placed on standby." During 2006, DOE/LLNL continued to await agency approval to shut off the treatment system and expects to shut off the eastern GSA treatment system in early 2007. As required, groundwater monitoring will be conducted to determine if VOC concentrations rise or "rebound" above cleanup standards after extraction ceases. No additional action is expected to be needed unless monitoring indicates that VOC concentrations rebound. Total VOC concentrations in Qal-$Tnbs_1$ HSU groundwater beneath the eastern GSA are shown of Dibley et al. (2007), Figure 2.1-5. The *Draft* and *Final Five-Year Review Report for the General Services Area* (Dibley et al. 2006a, 2006b) were submitted to the regulatory agencies by their due dates (see **Table 8-3**).

Contaminated groundwater is extracted from 8 wells and vapor is extracted from 7 wells screened in the Qt-$Tnsc_1$ HSU in the central GSA. Total VOC concentrations in central GSA groundwater have been reduced from 272,000 µg/L in 1993 to 360 µg/L in October 2006. From 1994 through the end of 2006, total VOC concentrations in the central GSA soil vapor extraction influent stream were reduced from 450 parts per million on a volume-per-volume basis ($ppm_{v/v}$) to 13 $ppm_{v/v}$. VOC concentrations in individual central GSA soil vapor extraction wells have also been significantly reduced. Total VOC concentrations in groundwater beneath the central GSA are shown in Dibley et al. (2007), Figure 2.1-6, and TCE concentrations in soil vapor in the central GSA are shown in Figure 2.1-7.

At Building 834, prototype weapons components were subjected to a variety of environmental stresses including heat and pressure. TCE was used as a heat-exchange fluid and was circulated in piping that sometimes leaked. There are three HSUs beneath the Building 834 OU. These are in descending order, the Tpsg, Tps-$Tnsc_2$, and $Tnbs_1$ HSUs. The first two HSUs contain contaminants. The maximum 2006 total VOC concentration in groundwater at Building 834 was 221,000 µg/L. This concentration was found in dense claystones of the Tps-$Tnsc_2$ HSU, which underlies the Tpsg HSU, and is considered an

aquitard. The concentrations in this HSU have remained relatively stable, as no active remediation has been done within the HSU owing to the negligible water yields of wells completed in it. Within the Tpsg HSU, which contains the bulk of the TCE in the OU, VOC concentrations in 2006 were a maximum of 65,223 μg/L. The historical maximum total VOC concentration in the Tpsg HSU was 1,060,000 μg/L in 1993. This maximum occurred in the Tpsg HSU within the core area of the OU, where despite pumping and treating of groundwater, VOC concentrations have stayed relatively stable over the last few years. This stability may be the result of continued dissolution of residual free-phase TCE. However, when compared to VOC concentrations prior to active groundwater and vapor extraction, the concentrations are lower. The average TCE concentration within the Tpsg HSU in the core area between 1993 and 1994 was 84,000 μg/L. This has dropped to an average core area TCE concentration of 8000 μg/L in the last two years. Total VOC concentrations in Tpsg-hosted groundwater beneath the Building 834 area are shown in Dibley et al. (2007), Figure 2.2-4. Groundwater and soil vapor extraction and treatment systems have been operating at Building 834 since 1995 and 1998, respectively. Thirteen wells that extract both groundwater and soil vapor compose the extraction network. The groundwater treatment system treats VOCs, nitrate, and organosilicate oil within the shallow Tpsg HSU and the vapor extraction system treats VOCs within shallow groundwater and the vadose zone. Maximum detected 2006 concentrations of nitrate and organosilicate oil in groundwater at Building 834 were 330 mg/L and 15,000 μg/L, respectively. Maps of the distribution of these two chemicals in Building 834 OU Tpsg HSU groundwater are depicted in Figures 2.2-6 and 2.2-8, respectively, of Dibley et al. (2007). Although VOC mass at Building 834 has been destroyed by *in situ* bioremediation, this mass has not been quantified.

At the High Explosives Process Area (HEPA) OU, high explosives are pressed and formed. Surface spills from 1958 to 1986 resulted in the release of contaminants at the former Building 815 steam plant. Subsurface contamination is also attributed to high explosives (HE) waste water discharges to former unlined rinse-water lagoons. Nine extraction wells in the OU pump groundwater that is treated at 6 treatment facilities (B815-SRC, B815-PRX, B815-DSB, B817-SRC, B817-PRX, and B829-SRC). Total VOCs, the HE compound RDX, perchlorate, and nitrate concentrations in $Tnbs_2$ HSU groundwater beneath the HEPA are shown in Figures 2.4-4, 2.4-6, 2.4-7, and 2.4-9, respectively, of Dibley et al. (2007). Maximum 2006 total VOC concentrations of 44.3 μg/L were detected in groundwater in the $Tnbs_2$ aquifer. The maximum historical total VOC concentration in this HSU was 110 μg/L in a water sample collected in 1992. The total VOC concentrations in source area groundwater samples have been reduced by about 45% since remediation began in 1999. RDX concentrations in $Tnbs_2$ HSU groundwater have decreased from a maximum of 200 μg/L detected in 1992 to a maximum in 2006 of 77 μg/L. The maximum 2006 concentrations of nitrate and perchlorate in the $Tnbs_2$ HSU in the HEPA OU were 89 mg/L and 35 μg/L, respectively.

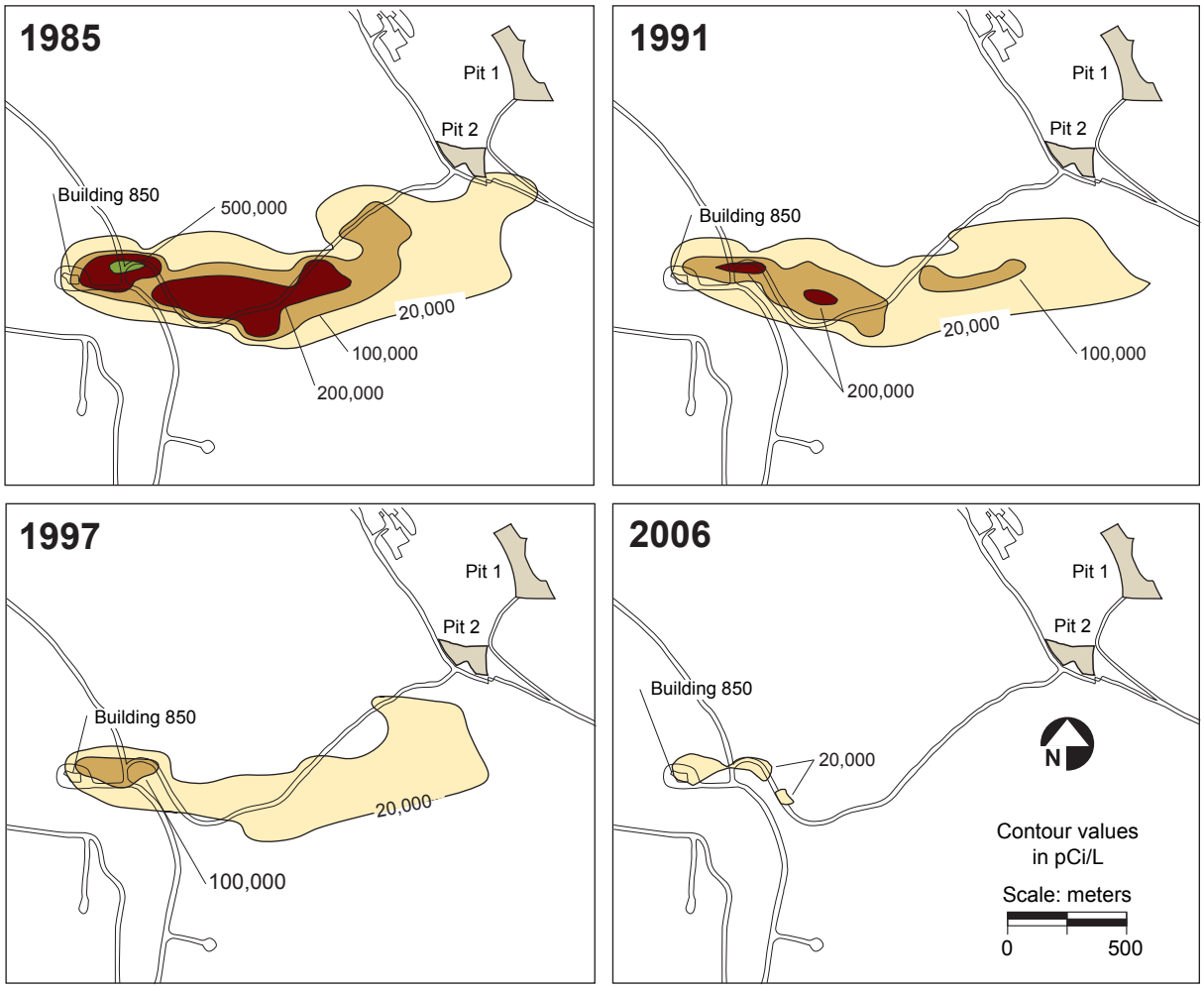


Figure 8-7. Tritium plume in combined Qal and $Tnbs_0$ HSUs during four time periods.

Building 850 is an explosives firing table. The distributions of tritium, uranium, nitrate, and perchlorate in Qal/WBR and $Tnbs_0/Tnbs_1$ HSU groundwater beneath the Building 850 OU are shown in Figures 2.5-4 through 2.5-11 of Dibley et al. (2007). During 2006, the maximum detected tritium activity in groundwater at the Building 850 OU was 92,700 pCi/L. The maximum historical tritium activity was 566,000 pCi/L in 1985. Monitored natural attenuation (MNA) is the selected remedy for the remediation of tritium in groundwater emanating from the Building 850 area. MNA continues to be effective for tritium in that the extent of the 20,000 pCi/L MCL contour has greatly diminished with the highest tritium activities located immediately downgradient of the firing table source area (see **Figure 8-7**). The maximum 2006 total uranium activity in groundwater that contains some depleted uranium was 19 pCi/L and was collected from a well proximal to the firing table. Total uranium activities everywhere in the OU continue to be below the 20 pCi/L state MCL. The maximum nitrate and perchlorate concentrations detected in 2006 in Building 850

OU groundwater were 140 mg/L and 64 μg/L, respectively. Because groundwater samples from a number of wells contain perchlorate in excess of the 6 μg/L State Public Health Goal, a remedial strategy for the perchlorate is being developed. A treatability test of lactate-mediated *in situ* bioremediation of the perchlorate is planned for 2007. Excavation and on-site solidification of over 16,000 cubic yards (yd^3) of PCB-bearing soil from the slopes around the firing table is planned for 2008.

The Building 854 OU is another site where weapons components were subjected to mechanical and thermal stresses and where pipes containing TCE leaked. Eight extraction wells pump $Tnbs_1/Tnsc_0$ HSU groundwater that is treated at three treatment systems (B854-SRC, B854-PRX, and B854-DIS) to remove VOCs, nitrate, and perchlorate. B854-DIS began operation in July 2006 to limit the downgradient migration of VOCs at the foot of the VOC plume. The expansion of the B854-SRC and B854-DIS extraction well fields was completed by the regulatory due date of September 29, 2006 (see **Table 8-3**). A soil vapor rebound test will be conducted at B854-SRC during 2007. The 2006 maximum total VOC concentration in groundwater was 180 μg/L, down from a historical maximum total VOC concentration of 2900 μg/L detected in 1997. Maximum 2006 concentrations of perchlorate and nitrate detected in the OU were 30 μg/L and 52 mg/L, respectively. Total VOC concentrations, perchlorate, and nitrate in $Tnbs_1/Tnsc_0$ HSU groundwater beneath the Building 854 OU are shown in Figure 2.6-3, 2.6-4, and 2.6-5, respectively, of Dibley et al. (2007).

Pit 6 received waste from 1964 to 1973. The landfill was capped and closed under CERCLA in 1997. MNA is the selected remedy for the remediation of VOCs in groundwater emanating from Pit 6. The maximum 2006 groundwater total VOC concentration was 8.5 μg/L and the maximum 2006 groundwater tritium activity was 1200 pCi/L. Historical maxima for these two contaminants were 290 pCi/L and 3,420 pCi/L, respectively. The maximum 2006 concentrations of perchlorate and nitrate in Pit 6 groundwater were 10 μg/L and 200 mg/L, respectively. The distributions of total VOCs, tritium, perchlorate, and nitrate in $Qt\text{-}Tnbs_1$ HSU groundwater at Pit 6 are shown in Figures 2.3-3 through 2.3-6 of Dibley et al. (2007).

Building 832 Canyon OU facilities were used to test the stability of weapons components under a variety of environmental stresses. Contaminants were released from Buildings 830 and 832 through piping leaks and surface spills. Three groundwater extraction and treatment systems (B832-SRC, B830-SRC, and B830-DISS) operate in the OU to remove VOCs, nitrate, and perchlorate. B832-SRC and B830-SRC extract and treat both groundwater and soil vapor. The other facility only treats groundwater. A fourth treatment facility (B832-PRXN) operated in the OU from October 2000 through April 2006. The extraction well for the former facility B830-PRXN facility was connected to B830-SRC before the September 23, 2006, milestone date. The expansion of the B832-SRC groundwater extraction well field to the distal portion of the total VOC plume was also completed prior to this milestone date. There are 17 extraction wells in the OU. VOCs, nitrate, and perchlorate occur

principally in the Qal/WBR, $Tnsc_{1a}$, $Tnsc_{1b}$, and Upper $Tnbs_1$ HSUs. The maximum 2006 groundwater TVOC concentration of 9600 µg/L was found in the $Tnsc_{1b}$ HSU. Maximum 2006 TVOC concentrations of 60 µg/L, 481 µg/L, and 1200 µg/L were detected in the Upper $Tnbs_1$, $Tnsc_{1a}$ and Qal/WBR HSUs, respectively. Total VOC concentrations during 2006 in groundwater from the four principal HSUs at the Building 832 Canyon OU are shown in Figures 2.7-6 through 2.7-9 of Dibley et al. (2007). Maximum perchlorate and nitrate concentrations detected in 2006 groundwater samples were 18 µg/L and 200 mg/L, respectively. Perchlorate and nitrate concentrations in HSUs at Building 832 are shown on Figures 2.7-10 through 2.7-17 of that document. The *Final Interim Remedial Design Report for the Building 832 Canyon OU* (Madrid et al. 2006) was submitted to the regulatory agencies by the February 23, 2006, milestone date.

The Site 300 Site-Wide OU is composed of release sites at which no significant groundwater contamination and no unacceptable risk to human health or the environment is present. For this reason, a monitoring-only remedy was selected for these release sites, which include the Building 801 Firing Table/Pit 8, Building 833, Building 845 Firing Table/Pit 9, Pit 2, and Building 851 Firing Table areas. The results of routine monitoring of these sites are in Dibley at al. (2007), Section 2.8, and Chapter 3.

8.2.4 Ongoing and Planned Investigations and Cleanup Activities

The following sections describe the current status of investigations underway at four sites (Pit 7 Complex, Building 865 Study Area, Building 812 Study Area, and Sandia Test Site) that are still under investigation and have not yet reached the Record of Decision for a final remedy to address environmental contamination.

8.2.4.1 Pit 7 Complex

The Pit 7 Complex comprises 4 landfills (Pits 3, 4, 5, and 7) that received waste from explosives experiments conducted at Site 300 firing tables. Pits 3 and 5 have released tritium to groundwater. Pits 3, 5, and 7 have released depleted uranium to groundwater. The maximum tritium activity detected in groundwater in 2006 in the OU was 328,000 pCi/L in the $Tnbs_0$ HSU. The maximum detected total uranium activity in groundwater that contained some depleted uranium was 110 pCi/L and was detected in a sample from the Qal/WBR HSU. Maximum concentrations of perchlorate, nitrate, and TCE detected in groundwater beneath the Pit 7 Complex in 2006 were 15 µg/L, 71 mg/L, and 4 µg/L, respectively. DOE/LLNL submitted the *Final Proposed Plan for Environmental Cleanup at the Pit 7 Complex Lawrence Livermore National Laboratory Site 300* (U.S. DOE 2006f) by the March 21, 2006, milestone date (see **Table 8-3**). The *Draft Amendment to the Interim Site-Wide Record of Decision for the Pit 7 Complex* at *Lawrence Livermore National Laboratory Site 300* (U.S. DOE 2006a) was also submitted by its milestone date of July 10, 2006. These two documents describe the contaminant hydrogeology at Pit 7 and the preferred alternative selected by the regulatory agencies and DOE. As discussed in these documents, DOE/LLNL will install a drainage

diversion system to prevent groundwater from entering the landfills and a treatment facility (PIT7-SRC) to remove uranium, nitrate, perchlorate, and VOCs from extracted groundwater.

8.2.4.2 Building 865 Study Area

Building 865 is a former linear accelerator, the Advanced Testing Accelerator. Freon-113 was used as a de-greaser there and has been released to groundwater. The maximum Freon-113 concentration detected in groundwater during 2006 was 290 μg/L. Freon-11 has also been detected in Building 865 groundwater at a maximum 2006 concentration of 1.5 μg/L. These values are below the federal and state MCLs for Freon-113 and Freon-11 in drinking water of 1200 and 5 μg/L, respectively. During 2006, DOE/LLNL submitted the *Characterization Summary Report for the Building 865 Study Area* (Ferry and Holtzapple 2006) to the regulatory agencies by the due date (see **Table 8-3**). This report details the hydrogeology and nature and extent of contamination emanating from Building 865. In addition to Freon-113 and Freon-11, a maximum of 10 μg/L of PCE and 9.6 μg/L of perchlorate were detected in Building 865 groundwater in 2006.

8.2.4.3 Building 812 Study Area

Building 812 is an explosives test firing table that is still active. During 2006, a maximum detected groundwater activity of total uranium, in which some of the uranium was due to addition of depleted uranium, was 65 pCi/L. Other chemicals detected in groundwater in excess of regulatory guidelines include perchlorate, total VOCs, and nitrate at maximum 2006 concentrations of 11 μg/L, 52.6 μg/L, and 74 mg/L, respectively. In *Characterization Summary Report for Building 812,* Ferry and Holtzapple (2005a) identified a plume of depleted uranium in groundwater and surface soil containing uranium isotopes in excess of Preliminary Remediation Guidelines (PRGs). A treatability study of pumping and treating Building 812 groundwater containing depleted uranium and other chemicals will begin in 2007.

8.2.4.4 Sandia Test Site

The Sandia Test Site was used in the past for several open air explosives experiments. Anthropogenic contamination has not been observed in samples of water, soil, or rock collected from the Sandia Test Site (Ferry and Holtzapple 2005b).

8.2.5 Environmental Impacts

LLNL strives to reduce elevated risks arising from chemicals released to the environment at Site 300 and to conduct its activities to protect ecological resources. At each OU, LLNL proposes a range of remediation options that are applicable for each release site. The option that achieves the goals of reducing risks to human, health and the environment and satisfying remediation action objectives, regulatory standards for chemicals in water and soil, and other state and federal requirements are then negotiated by DOE and the regulatory agencies with public input. The agreed-upon actions are then implemented. These actions have included

groundwater and soil vapor extraction and treatment, source area (lagoon and landfill) capping, monitored natural attenuation, monitoring, and institutional controls.

All ground-disturbing activities, such as well drilling, constructing treatment systems, excavating and constructing drainage structures, and sampling groundwater are planned and conducted to minimize disturbance of animal and plant habitat. A biologist inspects all sites and makes recommendations that are incorporated into the plan for each activity. Erosion controls and other recommendations made by surface water hydrologists are also incorporated into the plans for ground-disturbing activities.